Synopsis

STUDY OF PHOTON INTERACTION PARAMETERS FOR SOME GAMMA RAYS SHIELDING MATERIALS

Submitted by

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INTRODUCTION:

Future seek new source of energy to fulfill its requirements and nuclear energy seems to be the only solution. Visualizing the ever increasing requirements of energy, many countries are planning to construct nuclear reactors. However, the processes occurring in nuclear reaction (fission) leaves the daughter products in the excited states, which de-excites with the emission of highly penetrating radiations (X-rays or gamma rays). Further the exposure for longer duration of these highly penetrating radiations is harmful for living tissues.

The recent nuclear reactor explosion in Fukushima, Japan (2011) emphasized the dire need of systematic and precise studies of photon interaction parameters of different gamma rays shielding materials. Moreover, for the effective and harmless utilization of X-rays and gamma rays in different fields, the knowledge of photon interaction parameters such as mass attenuation coefficient, effective atomic number, electron density, penetration depth and buildup factor of these highly penetrating radiations with different type of gamma rays shielding materials are precisely required. The brief introduction to different photon interaction parameters is as follows:

Mass attenuation coefficient (μ_m) measures the probability of interaction (absorption/ scattering) of photon with the interacting medium. It is measured in cm^2/g. It is the fundamental tool to derive many other photon interaction parameters such as molecular cross-section, atomic cross-section, electronic cross-section, equivalent and effective atomic numbers, electron density, KERMA, buildup factor etc.

Effective and Equivalent atomic number (Z_{eff} & Z_{eq}) are parameters similar to the atomic number of elements, which describes the properties of the composite materials (compounds/mixture) in terms of equivalent elements. Effective atomic number (Z_{eff}) is computed from the contribution of all partial photon interaction processes in different incident photon energy regions, whereas equivalent atomic number (Z_{eq}) is computed from the contribution of Compton scattering processes only. Hence, these are dimensionless quantities. However, these are energy dependent parameters.

Electron density (N_e) measures the number of electrons per unit mass of the interacting material; hence it is also known as effective electron number. It is measured in electrons/g. Higher is the value of electron density; more are the chances of photon interaction.

Penetration depth of the interacting material is measured in the units of mean free path (mfp), where one mean free path (mfp) represents the average distance between two successive interactions of photons which results in decreasing the intensity of incident photon beam by the factor of 1/*e*. It is equal to the reciprocal of linear attenuation coefficient. Since, the linear attenuation coefficient is an energy dependent parameter; therefore the value of mean free path also varies with the variation in incident photon energy.

Buildup factor is the correction factor in the well known Lambert-Beer Law ($I = I_o e^{-\mu x}$). It is an important parameter in describing the distribution of photon flux in the interacting material. The main (dominant) photon interaction processes are photoelectric effect, Compton scattering and pair production. Out of these interaction processes, photoelectric effect and pair-production results in complete absorption/elimination of the photon, whereas Compton scattering results in energy degradation only. Hence, Compton scattering results in buildup of lower energy photons in the medium, which can be estimated by a factor called the 'build-up factor'.

The Lambert-Beer Law which provides the relationship between gamma ray intensities before (I_o) and after (I) passing through the interacting material of finite thickness (x) and linear attenuation coefficient (μ). This law is applicable only if the following three conditions are realized: i) Radioactive source must be mono-energetic, ii) Target/interacting material must be thin (so as to have a single interaction), iii) Narrow beam geometry must be used. In case, any of these conditions were violated, then the modified Lambert-Beer Law ($I = B\, I_o e^{-\mu x}$) is used for the intensity relation, where **B** represents the Buildup factor.

REVIEW OF LITERATURE:

The mass attenuation coefficient data for about all the elements is compiled up in the form of software packages: XCom by Berger and Hubbell (1987) and WinXCom by Gerward et al.

(2001). However, the work is still in progress to find out mass attenuation coefficients of different compounds and mixtures. The research work concerned with the experimental measurement of mass attenuation coefficient had started in 1930's and still it is in progress for different type of materials. Hence, it is very difficult to mention all the studies related with it. The recent studies performed in this direction are by Sahin (2011) for PbO, barite and some boron ores.

The concept of effective atomic number for compounds and mixtures has been introduced for the very first time by Hine (1952). According to him, the effective atomic number of a material composed of several elements cannot be expressed by a single number and for each of the different processes by which γ-rays can interact with matter, the various atomic numbers in the material have to be weighted differently. This number for compounds and mixtures is named as the ''effective atomic number" and it varies with the energy. Following his suggestions, many attempts have been made to determine effective atomic number (Z_{eff}) of different materials such as for commonly used solvents and acids by Singh et al (2007, 2007a), for alloys by Han and Demir (2009), for TSW and its compounds by Kurudirek et al. (2010), for some scientific samples by Singh et al. (2010), for boron compounds by Sahin (2011) and for different solid state detectors by Medhat (2011). It has been observed that the effective atomic number values have been computed mostly using the ratio of atomic to electronic cross-section method.

Different methods were used by various research groups to compute the buildup factors such as moments method by Eisenhauer and Simmons (1975), G.P. fitting method by Harima et al. (1986), invariant embedding method by Sakamaoto et al. (1988) and Shimizu (2002), iterative method by Suteau and Chiron (2005) and Monte Carlo method by Sardari et al. (2009)

Harima et al. (1986) reported that the absolute values of maximum deviations in exposure buildup factors for water in G.P. fitting are within 0.5–3% and it can reproduce the buildup factors with better accuracy. Shimizu et al. (2004) shown that the methods based on invariant embedding, G-P fitting and Monte Carlo simulation agree well for 18 low - Z materials with small discrepancies. American National Standards (ANSI/ANS-6.4.3, 1991) has provided gamma ray buildup factor data for 23 elements ($_4$Be - $_8$O, $_{11}$Na - $_{16}$S, $_{18}$Ar - $_{20}$Ca, $_{26}$Fe, $_{29}$Cu, Mo, Sn, La, Gd, W, $_{82}$Pb and $_{92}$U), one compound (water), two mixtures (i.e. air and concrete) at

energies in the range 0.015–15 MeV upto penetration depths of 40 mfp using the G.P. fitting method.

Recently, different researchers had contributed in providing gamma ray buildup factor data for different compounds and mixture using interpolation method based on ANS standard data such as for solvents by Singh et al. (2008), for polymers by Singh et al. (2009), for thermo-luminescent dosimetric materials by Manohara et al. (2010), for flyash-concretes by Singh et al. (2010), for human tissue by Kurudirek et al. (2011), for teeths by Manjunatha, Rudraswamy (2011) and Kurudirek, Topcuoglu (2011), for some essential amino acids, fatty acids and carbohydrates by Kurudirek and Ozdemir (2011), for samples from the earth, moon and mars by Kurudirek et al. (2011) in the energy range 0.015–15 MeV upto and upto the penetration depths of 40 mfp using the G.P. fitting method.

However, some deficiencies were observed in the American National Standards buildup factor data such as lack of self-consistency within the standard (the mass attenuation coefficients tabulated in the standard were not including coherent scattering) and more accurate attenuation coefficient data have become available (Chadwick et al., 2006). Hence, American Nuclear Society (ANS) had withdrawn the previous standard (ANS/ANSI 6.4.3) and in the process of revising the same.

OBJECTIVES:

Visualizing the future demands of adopting nuclear power as the new source of energy and the complexities, in case of nuclear accidents; the present proposal has been made with an aim:

- To measure the mass attenuation coefficient (μ_m) of some gamma ray shielding materials more precisely with better resolution Si-PIN detector (~170 eV) at some lower incident photon energies.
- To measure the effective atomic numbers for some compounds/mixtures at lower incident photon energy and provide justification for better theoretical formulation.
- To compare buildup factor on the basis of
    - Equivalent and Effective atomic numbers

- Different theoretical methods such as G.P. fitting method and IE method.
- Experimental and theoretical values for some shielding materials.

- To study the dependence of different photon interaction parameters on
  - Incident photon energy
  - Penetration depth
  - Effective/Equivalent atomic number of the material etc.

METHODOLOGY:

The computational work of photon interaction parameters for some gamma rays shielding materials includes the following steps:

Selection of Shielding Materials:

For shielding from gamma rays, the materials with higher atomic number (Z), higher density (ρ) are preferred. However, such materials are rare and hence costly. From several decades, thick concrete walls, steel/iron sheets were used as gamma rays shielding material at nuclear reactor sites, nuclear laboratories. Hence, photon interaction parameters for different types of conventional shielding materials will be precisely investigated for the efficient and harmless use of nuclear energy.

Computations of Mass Attenuation Coefficient (μ_m):

The mass attenuation coefficient values of partial photon interaction processes such as photoelectric effect, Compton scattering, pair production, Rayleigh scattering and total are available in the form of software package WinXCom by Gerward et al. (2001). By substituting the chemical composition/weight fraction of compound/mixture, the mass attenuation coefficient of the shielding materials will be generated in the energy range 1 keV - 100 GeV.

Computations of Penetration Depth (mfp):

The mass attenuation coefficient values of the selected shielding materials will be multiplied with the densities of the selected materials respectively to get linear attenuation coefficient and further taking the reciprocal of that will provide penetration depth in mean free path (mfp).

Computations of Equivalent and Effective Atomic Numbers (Z_{eq} and Z_{eff}):

The values of equivalent and effective atomic numbers for the interacting material can be computed by using the logarithmic interpolation method. For the computation of equivalent atomic number, the ratio R (μ_{Comp}/μ_{total}) of the interacting material has to be interpolated within the corresponding ratios (μ_{Comp}/μ_{total}) database of the elements at the same energy. Whereas, for the computation of effective atomic number, the attenuation cross-section (σ) of the interacting material has to be interpolated within the corresponding attenuation cross-section (σ) database of the elements at the same energy.

Moreover, different methods were observed from literature survey for measurement and computation of the effective atomic number such as

- Ratio of atomic to electronic cross-section method,
- Interpolation of attenuation cross-section method.

Hence, an attempt will also be made to compute effective atomic number using more than one method for comparative studies.

Computations of Buildup Factor (B):

The computation of buildup factor (energy absorption as well as exposure) will be done for the same selected materials of dosimetric interest using different methods

- Five parametric G.P. fitting method (b, c, a, X_k and d) and
- Invariant Embedding method

Some of the photon interaction parameters will be measured experimentally for some gamma rays shielding materials, which will be used in the verification and error analysis of the proposed work.

Finally, the dependence of photon interaction parameters of the selected shielding materials on different factors will be investigated such as

- Incident photon energy
- Chemical composition/nature of the materials (Z_{eq} and Z_{eff})
- Penetration depth (mfp)

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